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Progress Report on Mechanical Application of Fertilizers to Cotton in South Carolina 1931[1]

by

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INTRODUCTION

The study of the mechanical application of fertilizers to cotton has been in progress in South Carolina for three years. Progress reports have been published on the 1929(1) 2/ and 1930(2) work. During 1929

2/ Italic numbers in parenthesis refer to literature cited, p.

twenty-two representative fertilizer distributors were tested in both the field and laboratory. The field tests were made on two widely different types of soil.

In 1930 experiments were conducted on three soil types. The influences of the following factors on the germination and yield of the cotton were studied: placement of the fertilizer with respect to the seed; rate of application; irregularity of distribution; and particle size of the fertilizer. One special machine simultaneously planting the seed and applying the fertilizer was used in order to insure the most uniform conditions possible throughout the experiments.

These experiments were continued cooperatively during 1931 by the Clemson Agricultural College and Experiment Station, the National Fertilizer Association, and the Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering of the United States Department of Agriculture, in South Carolina at the Pee Dee Experiment Station, Florence, on Norfolk very fine sandy loam; at the Sand Hill Experiment Station, Columbia, on Norfolk coarse sand; and at Clemson College, on Cecil sandy clay loam. The purpose of the study was to secure further fundamental information which would serve as a basis for the development of more efficient distributing machines and the recommendation of more effective and safer methods of fertilizer application at planting time for cotton.

Janice S. Brown OCT 2 1932

INTRODUCTION

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FERTILIZERS

The fertilizers used in these experiments were standard commercial goods. The nitrogen was derived one-fourth from organic sources and three-fourths from ammonium compounds, and the potash from muriate. The results of chemical analyses and drillability measurements made on these mixtures are presented in Table 1. Analysis formulas wherever used in this report refer to percentages of NH_3, P_2O_5, and K_2O in the order named.

Table 1. Chemical analyses 1/ and drillability measurements of the fertilizers

Analysis Formula	Total N as NH_3	NH_3	Total P_2O_5	Available P_2O_5	K_2O	H_2O	Apparent Specific Gravity	Angle of Repose
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	g./cc	Degrees
4-8-4	3.98	3.12	9.67	7.57	4.28	3.06	1.03	39.5
8-16-8	7.93	5.94	17.87	17.63	8.32	3.83	.87	37.5

1/ Made by L. M. White, Junior Chemist, Bureau of Chemistry and Soils

SEED

Coker's Super Seven cotton seed of high germination were used in the tests at the Pee Dee and Sand Hill Stations. Dixie Triumph seed of high germination were used at Clemson College. All seed were delinted with sulphuric acid. In all cases the seed were planted at the rate of approximately one bushel per acre.

FERTILIZER PLACEMENTS

Twenty-six different placements of the fertilizer with respect to the seed or plant were used on the Norfolk very fine sandy loam, which was the largest number employed at any station. The total fertilizer appli-

cation at planting time was made in twenty-four positions and the application of a part of the fertilizer after thinning introduced the two additional placements. The numbers of placements used on the other soils differed somewhat according to the amount of land available. Descriptions of the placements are given in the tables of results.

Several tests were made in which the coverage of the seed and the treatment of the soil about the seed differed from those of the comparable standard tests.

EXPERIMENTAL MACHINE AND EQUIPMENT

A special combination planter and fertilizer distributor was built particularly to meet the requirements of this experimental work which necessitates a machine having greater accuracy, more equipment, and wider ranges of adjustments than might seem feasible or necessary for commercial machines. The general design of the machine is shown in Figure 1.

Figure 1.- Special combination planter and fertilizer distributor built under general specifications of the Bureau of Agricultural Engineering for fertilizer placement experiments

The soil-working tools are mounted on a sub-frame which can be adjusted vertically without change of inclination. Thus the whole assembly can be raised or lowered as required without affecting the relative placements of fertilizer and seed. The sub-frame equipped for normal operation in placing the fertilizer in a band below the seed is shown in Figure 2.

Figure 2.- Tool frame equipped for normal operation with furrowing shovel attached to place the fertilizer in a band below the seed. A, Furrowing shovel for placing the fertilizer; B, bedding disks; C, seed shoe; D, adjustable wings to regulate depth of planting; E, press (covering) wheel

All soil-working tools except the press wheel are held rigidly to the frame. The shovel, A, has wings attached for excluding the soil until the fertilizer

[illegible] in furrows, [illegible] was made [illegible] twenty-four positions [illegible] part of the [illegible] elsewhere [illegible] for the additional placements. The amount of [illegible] used on the [illegible] differed according to the amounts of land available. [illegible] of the placements were given in the tables of results.

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EXPERIMENTAL MACHINE AND EQUIPMENT

A special machine for planter and fertilizer distributor was built particularly to meet the requirements of this experimental work, which necessitated a variable hopper, greater accuracy, more uniformity, and other features of placements than might seem feasible or necessary for commercial machines. The general features of the machine is shown in Figure 1.

Figure 1.- Complete, [illegible] planter and fertilizer distributor built under general specifications of the Bureau of Agricultural Engineering for fertilizer placement experiments.

The soil-working tools were mounted on a tool-bar which can be adjusted vertically [illegible]. Thus the whole assembly can be raised or lowered as required without affecting the relative placement of fertilizer and seed. The tool-frame equipped for vertical operation in placing the fertilizer in a band below the seed is shown in Figure 2.

Figure 2.- Tool frame equipped for vertical operation, [illegible] placed to place the fertilizer in a band below the seed: [illegible] fertilizer; [illegible]; [illegible].

[illegible] were held [illegible] of the frame, [illegible] the fertilizer

is deposited in the furrow, in order to maintain a constant width and placement of the fertilizer band. The purpose of the bedding disks, B, is to cover the fertilizer and throw an excess of soil in front of the seed shoe, C. Thus any depressions are filled, which permits a constant relative height of the seed with respect to the fertilizer as well as uniform covering of the seed. The lateral wings, D, attached to the seed shoe, lower the seed bed to a constant height and thus not only regulate the depth of planting but also insure a uniform depth of planting. The press wheel, E, is of the open type and is free to exert constant pressure for covering the seed and for firming the soil.

Figure 3 shows the manner of attaching and adjusting, both verti-

Figure 3.- Mounting on tool frame of single-disk furrow openers with both lateral and vertical adjustment for placing the fertilizer in bands at each side of the seed. A, Single-disk furrow opener B, stirring shovel

cally and laterally, a pair of single disk furrow openers, A, for placing the fertilizer in narrow bands at the sides of the seed. The soil lying between the disks in which the seed are planted is not disturbed in normal operation. In certain tests, however, it seemed desirable to make comparisons of seed planted in disturbed and undisturbed soil. In this case, the shovel, B, was attached to stir the soil in which the seed were planted.

Figure 4 shows the tools used for mixing the fertilizer with the soil

Figure 4.- Arrangement of shovels on tool frame for mixing the fertilizer with the soil below the seed. A, Shovel for opening furrow in which fertilizer is deposited; B and C, mixing shovels

below the seed. The fertilizer is first deposited in a furrow 4 inches wide opened by the shovel, A. The two small shovels, B and C, each in turn lift certain quantities of the fertilizer and soil and mix them to a considerable extent. Fertilizer is not readily mixed with a damp soil. For that reason

thorough mixing, as usually conceived, could probably not be obtained by any simple arrangement on a combined planter and distributor.

For placing all or a part of the fertilizer in contact with the seed a delivery tube was attached at the rear of the seed shoe.

A small press wheel, A, attached at the rear of the seed shoe as shown in Figure 5 was used in certain tests to press the seed into the furrow.

Figure 5.- Press wheel and blade coverers attached at rear of seed shoe for pressing seed to desired depth and covering with loose soil. A, Press wheel, diameter 10 inches, width of tire 1.25 inches. B, Blade coverers.

Blade coverers, B, then covered the seed with loose soil. For example, when the depth of planting is one inch the seed are first deposited in a very shallow furrow and pressed about 0.75 inches further into the soil. The possibilities of this arrangement are to aid in establishing capillarity below the seed and to reduce the formation of crust above the seed.

The fertilizer dispensing mechanism is of the revolving-cylinder top-delivery type. The plunger rises a definite distance for each revolution of the drive wheel and thus dispenses the fertilizer at a constant rate. For a particular soil type, variation in the slippage of the drive wheels which would give a corresponding variation in the delivery rate has been found to be negligible when the seed bed is well prepared. The average per cent wheel slippage recorded for each soil type is as follows: very fine sandy loam 13.4 ± .05, coarse sand 13.7 ± .01, sandy clay loam 12.4 ± .03 The only possibility for material variation in the application rate is in the compacting of the fertilizer in the hopper during operation. By thoroughly settling the fertilizer in the hopper before operation started, a practically constant delivery rate was obtained. By first determining the weight of fertilizer held by the hopper and the number of revolutions of the drive wheel for any known distance under the field conditions, delivery rate

adjustments can be determined mathematically since the dispensing action is positive.

The hopper has been provided with four delivery openings and tubes. In those tests where a part of the fertilizer was placed in contact with the seed and the balance on both sides of the seed, three delivery tubes were required. The delivery rate through any tube can be positively controlled by the adjustable delivery blades, A, as shown in Figure 6. By adjustment

Figure 6.- Fertilizer hopper head with four delivery openings and adjustable delivery blades. A, Delivery blade with slot adjustment at outer end

of the delivery blades the whole delivery can be diverted into one tube or in any desired fractional parts into two or more tubes.

No rate of application differed more than about one per cent from that desired. The variation in rate of application among the six rows of individual tests was approximately the same for all fertilizers, the average deviation being .2 per cent.

The fertilizers were distributed along the row with a high degree of uniformity. The average coefficient of variation as determined by the method described in a previous report(1) was 8.8 per cent, based on one-foot intervals.

LAYOUT OF THE EXPERIMENTS

The project was primarily a study of fertilizer placement, although the use of single and double strength fertilizers in the placement tests affords a comparison of the two materials. Determinations were made on the movement and concentration of salts in the soil. The criteria upon which relative efficiencies were based are concentration of salts in the root zone, germination and yield.

The various placements and treatments were arranged in single rows,

in different series. Six series were planted at the Pee Dee Station, six at the Sand Hill Station, and five at Clemson College. The rows were spaced 3.5 feet apart. Each plat consisted of one row 124.5 feet long. Observations were made on two 50-foot lengths in each row, $12\frac{1}{4}$ feet at each end being discarded. Thus, each germination and yield figure shown for the very fine sandy loam (Pee Dee Station) and the coarse sand (Sand Hill Station) represents the average of 12 observations, while those shown for the sandy clay loam (Clemson College Station) represent an average of 10 observations.

The order of the tests was arranged to avoid extreme differences in final stand of adjacent rows. Thus, significant differences in plant competition were largely eliminated.

Five unfertilized checks were equally spaced throughout each series. In planting the seed for the unfertilized tests, different furrowing tools which were used to obtain fertilizer placements were mounted on the machine. This procedure seemed desirable since the soil about the seed is not disturbed to the same extent in obtaining the various fertilizer placements. If differences in the rapidity of germination occurred with the seed planted in firm soil and disturbed soil, they might account, in part, for the differences among fertilizer placements, particularly with respect to germination. The soil treatment for each check is given in Table 3.

The unfertilizer checks were arranged in such a manner that they did not lie adjacent to the same tests throughout the series of replicate plots. An unfertilized check was adjacent to only one plat of each test. The following example of 36 tests shows the location of checks, X, Y, and Z:

		X	Y	Z
For Series	A, Between tests	1 and 2	13 and 14	25 and 26
" "	B,	3 and 4	15 and 16	27 and 28
" "	C,	5 and 6	17 and 18	29 and 30
" "	D,	7 and 8	19 and 20	31 and 32
" "	E,	9 and 10	21 and 22	33 and 34
" "	F,	11 and 12	23 and 24	35 and 36

This arrangement placed all tests on the same basis in regard to proximity to unfertilized rows.

SOIL MOISTURE AND RAINFALL

The soil moisture on various dates and the rainfall are given in Table 2. Daily rainfall records are shown only for the periods in which certain records were dependent largely on the amount and distribution of the rainfall. It will be observed that the total rainfall for the period of the experiment is below normal at each station. However, at all stations the rainfall during the month of May, which largely includes the germination period, was considerably above normal but during June and September the rainfall was exceptionally low.

GERMINATION

Attention has been called to the favorable moisture conditions during the germination period. Seed were planted on the very fine sandy loam having 9.0 per cent moisture on April 16 and 17. Good rains fell on the 20th, 22nd, 23d, and 27th. On the 23d of April .38 inches of water fell in a dashing rain which greatly packed the soil. A number of plants were in the crook stage and most of these did not survive. This rain was

followed by a rather prolonged period of cold weather which materially delayed and injured germination. Furthermore, an exceptionally large number of the plants died before the last stand count just prior to thinning.

The 5.35 per cent moisture content of the coarse sand at time of planting on April 21 and 23 was favorable for germination of the cotton seed. A good rain fell on the 27th. Temperatures, possibly a little below normal immediately after planting, did not greatly retard germination.

The moisture content of the sandy clay loam at time of planting on May 1 was also favorable for germination. A 0.9-inch rain fell immediately after planting. A 2.8 inch rain fell on the next day and heavy rains followed on May 5, 6, and 7. Cool weather which accompanied the heavy rains slightly delayed germination. With 8 inches of rain falling during the week following planting, no injury to germination would be expected from fertilizer applied in any reasonable manner on this comparatively heavy soil.

The treatment of the soil about the seed differs among the unfertilized checks to correspond to the treatment for representative fertilized tests. The germination for the unfertilized tests as measured by the number of plants appearing above ground is given in Table 3. The results are rather inconsistent for the Norfolk very fine sandy loam, presumably due to the adverse weather and soil conditions during the germination period. For the coarse sand and sandy clay loam, stirring of the soil to a depth of 3 inches below the seed not only delayed germination but resulted in fewer plants appearing above ground. There is some indication that planting the seed in Norfolk coarse sand undisturbed to a distance of either 1.5 or 3.5 inches to each side gave the most rapid germination and the largest number of plants.

Placement

The germination as measured by the number of plants appearing above ground or come-up is shown for various placements of 800 pounds per acre of 4-8-4 fertilizer in Table 4. The come-up counts on the very fine sandy loam and the coarse sand were of the same order and striking differences will be noted among the tests. Serious injury to germination occurred on the sandy soils where the fertilizer was placed either in a 1.75 or 3.5-inch band at a depth of 3 inches or less below the seed, the damage being particularly serious where the fertilizer was placed 1 inch below the seed. No deterrent effects on germination were noticeable with the fertilizer placed 4 inches below the seed.

Comparison of tests Nos. 2 and 5 in which the soil below the seed had been stirred shows no advantage of pressing the seed in the furrow and covering with loose soil on the very fine sandy loam where heavy rains fell immediately after planting; however, on the coarse sand compacting the soil on which the seed were planted was a distinct advantage.

On the sandy soils application of fertilizer in bands at the sides of the seed resulted in better germination than where applied in bands at the same depths directly below the seed. In fact, germination for the side placements was, in general, equally as good as for the unfertilized checks. The stand and early growth of cotton where the fertilizer was applied in the Norfolk coarse sand at different depths directly below the seed and at the sides of the seed are shown in Figure 7.

Figure 7.- Cotton planted April 23, photographed June 23 on Norfolk coarse sand, Columbia, S. C., 4-8-4 fertilizer applied at 800 pounds per acre in the following placements with respect to the seed: (a) In contact with seed; (b) in band 4 inches wide, 1 inch below; (c) 2 inches below; (d) 3 inches below; (e) 4 inches below the seed; and (f) in narrow bands at each side of the seed 3 inches below; (g) 2 inches below; (h) 1 inch below the level of the seed

The poorest stand with placements at the sides of the seed was obtained where the fertilizer was applied in bands $1\frac{1}{2}$ inches to the sides and 1 inch below the level of the seed. Comparing test 17 with 14 in which the soil below the seed had not been stirred, it is apparent that under prevailing conditions pressing the seed in the furrow was of no advantage on the very fine sandy loam or the coarse sand.

Placing of 1/8 or 1/4 of the application of 800 pounds per acre in contact with the seed and the remainder either in bands below or at the sides of the seed resulted in serious injury to stand on the sandy soils. Least injury occurred in these partial contact placements where 1/8 of the fertilizer was applied with the seed and the remainder in bands $3\frac{1}{2}$ inches to each side and 2 inches below the level of the seed. Placing the total fertilizer application in contact with the seed resulted in very serious injury.

Mixing of the fertilizer with the soil below the seed as accomplished in these tests resulted in serious injury to germination and unsatisfactory stands.

Good stands were secured with all placements used on the sandy clay loam, except where the fertilizer was applied in contact with the seed. A marked delay in germination occurred where 1/8 or 1/4 of the fertilizer was applied in contact with the seed and the remainder either in bands at the sides of or in a band below the seed. Application of 1/4 as compared to 1/8 of the fertilizer in contact with the seed and the remainder in bands $3\frac{1}{2}$ inches to the sides and 2 inches below the level of the seed resulted in appearance of fewer plants above ground, although the stand was not seriously affected in either case.

Rate of Application

On the sandy soils increasing the rate of application of 8-16-8 fertilizer from 200 to 400 and 600 pounds per acre, as shown in Table 5, resulted in a reduced number of plants appearing above ground where applied in a 1.75-inch band 2 inches below the seed and where mixed with the soil. This is illustrated in Figure 8, A and B. Increase in rate of application showed

Figure 8.- Cotton planted April 16, photographed June 25, on Norfolk very fine sandy loam, Florence, S. C., 8-16-8 fertilizer applied as follows: A, 1.75-inch band 2 inches below the seed; (a) 200 pounds per acre; (b) 400 pounds per acre; (c) 600 pounds per acre. B, Mixed with the soil below the seed; (a) 200 pounds per acre; (b) 400 pounds per acre; (c) 600 pounds per acre. C, Bands 3.5 inches to each side of and 2 inches below the level of the seed: (a) 200 pounds per acre; (b) 400 pounds per acre; (c) 600 pounds per acre

no significant effect upon the number of plants where the fertilizer was applied in bands at the sides of the seed. (Fig. 8C) At all rates of application the germination was materially better for the placement at the sides of the seed.

No serious effect on stand resulted from applications of 8-16-8 fertilizer on the sandy clay loam at any rate or placement used, although there was a noticeable delay in germination and a slight reduction in number of plants where the fertilizer was mixed with the soil at the heavier rates.

SINGLE VERSUS DOUBLE STRENGTH FERTILIZERS

A comparison of the results for placements 2, 14 and 24 (Table 4) where 800 pounds per acre of 4-8-4 fertilizer were used, with results of corresponding placements of 400 pounds per acre of 8-16-8 fertilizer in Table 5, shows no significant differences in the number of plants appearing above ground. However, in some cases on the sandy soils more plants appeared where 400 pounds per acre of the 8-16-8 fertilizer were applied.

MOVEMENTS OF SOLUBLE SALTS IN THE SOIL

A knowledge of how much soluble fertilizer remained where it was put and how much came into contact with the seed during the germination period are necessary to explain the effects of different placements on the crop. The amount by which the concentration of soluble salts in the seed zone of a fertilized row exceeds that of its unfertilized check may be used as a measure of the quantity of fertilizer that has been moved from its original location into contact with the seed. Accordingly, the concentrations of soluble salts in the seed zones were determined several times soon after planting for each treatment. Later in the season indications of the amount remaining where it was placed and the distance to which some of it had spread were also obtained.

Method of Determining Movements

Samples of soil were obtained for determinations of their soluble salt contents in the following manner: A hole was dug in the row about four inches deep and the side of the hole at right angles to the row was gradually cut away with a spatula until a seed was exposed as shown in Figure 9. A cork-borer was then pushed into the row with the seed inside

Figure 9.- Longitudinal section of a row showing the method of taking samples for determinations of the soluble salt in the seed zone

of it as illustrated. When the borer was removed it contained a core of soil one inch in diameter and 5 inches long with several seeds at its center. This soil is here considered to be the seed zone. Four such cores were gathered for each sample, screened through a 10 mesh sieve and thoroughly mixed. A 25 cc. sample of the fine soil was then placed in a 150 cc. wide mouthed bottle, 100 cc. of distilled water was added, the bottle was tightly closed and shaken at intervals during 24 to 36 hours. The soluble salts

content of the solution was determined with a Wheatsone bridge by the method developed by the U. S. Bureau of Soils.(3) This method was shown to give results sufficiently accurate for the present purpose by making the same determination on a few samples by a much longer but more accurate method and comparing the results.

PLACEMENT

The results given in Tables 6 and 7 show clearly that soluble salts were moved about rapidly in these soils. A few of the results appear to be out of line, probably due to taking samples at points that were not representative for the row. This was most likely to happen in the case of the mixed-with-the-soil placements because the degree of mixing was not uniform. This left more fertilizer near the seed at some points in the row than at others.

In most cases where the fertilizer had been placed in bands 2 inches oe less below the seed, or mixed with the soil, the quantity of salt in the seed zone was significantly higher than those of the checks the day after planting. In the Norfolk very fine sandy loam a slight amount of salt was brought into contact with the seed from a depth of 4 inches during a single day. In both the fine sandy loam and coarse sand the amount of salts in the seed zones increased rapidly when the fertilizer had been placed one or two inches below the seed. No fertilizer was carried into contact with the seed from the bands applied at the ordinary rate, 3½ inches to both sides of the seed, so far as observed. Very small amounts were moved into the seed zones, however, from bands placed 1½ inches to the sides at all depths tried but this was less marked from a depth of 3 inches below that of the seed. Salts were moved much more slowly and for shorter distances to the sides than upward and downward. The quantity coming into contact with the seed diminished rapidly as the distance increased from the seed

to the point where the fertilizer was placed, no matter what its direction happened to be.

The determinations for the very fine sandy loam on April 20 were made after a 0.30 inch rain which appeared to carry downward much of the soluble material in this soil. Thus in most cases the quantities of salts in the seed zones for a day or two were greatly reduced but where part of the fertilizer was placed on the surface of the soil the quantity was greatly increased by the same cause. This soluble material began to rise again almost immediately as indicated by determinations on April 22 in Table 6. The determinations made for this soil on April 30 and May 1 indicate that salts were being carried upward at this time and probably had been moved in this direction during most of the previous week.

Soil moisture in the coarse sand was maintained near a level of 5 per cent from planting time until May 12 by a succession of light rains with periods of capillary rise between them. This brought about a steady increase in the concentration of the salts in solution in the seed zones where the fertilizer was placed 1, 2, and 3 inches below the seed and where it was mixed with the soil until a heavy rain on May 12 greatly decreased it.

The first set of determinations for the Cecil sandy clay loam was made 8 days after planting, during which time over 8 inches of rain fell. The quantities of soluble salts in the seed zones in the Cecil soil were found to be very low compared with the other soils.

Rate of Application

Although from Table 7 no salt appears to have been carried into the seed zones from bands $3\frac{1}{2}$ inches to the sides of the seed at normal or half normal rates of application of 8-16-8 fertilizer in any of the soils or at the one and one-half rate in the coarse sand and sandy clay loam, small

amounts were thus carried at the highest rate in the very fine sandy loam. The quantity from this placement at the highest rate was about the same as, or slightly less than, that from the 1.75-inch band placed 2 inches below the seed or the mixed-with-the-soil placement at the lowest rate. From the latter two placements the amount of salt brought into the seed zone increased rapidly with increases in the rate of application.

Single Versus Double Strength Fertilizers

The two fertilizers may be compared by the results given in Table 7 for the double strength fertilizer with those for the same placements given in Table 6 for the 4-8-4 fertilizer. It appears that no salt was carried from placements $3\frac{1}{2}$ inches to the sides of the seed into contact with the seed where either fertilizer was used at the normal rate. In the case of the other placements, salt was carried into the seed zone from applications of both fertilizers. In all of the soils the quantity was greater when the ordinary strength fertilizer was used. This may be due to the fact that 100 pounds of the 4-8-4 contained 37 pounds of soluble salts, while the equivalent amount of 8-16-8 contained only 32 pounds.

Spread of Fertilizer Salts During the Growing Season

The amount of soluble salts present 100 days after planting was determined for various points extending from the surface of the soil to a depth of 15 inches in the row of plants and from the center of the fertilizer band to points 5 inches to the sides of it. The placement selected was the 1.75-inch band located 2 inches below the seed. In general the results obtained with this placement should apply to most of the others in the same soil. Cores of soil were taken for each point by inserting a cork borer parallel with the row and the soluble salt content of the composite sample was determined with the soil bridge in the manner previously described. Additional samples were then obtained in like manner from another plat for duplicate determinations.

Averages of these determinations are given in Table 8.

The 4-8-4 fertilizer contained 38 per cent of water soluble salts. A core of soil taken from the contact placement was estimated to consist of 9 parts of soil to 1 part of fertilizer. One day after planting such cores from the fine sandy loam and coarse sand contained 3.61 per cent and 4.54 per cent of total soluble salts, respectively, and thus at this time practically all of the salts were still present in the fertilizer band in a water-soluble condition. After 15 days, however, this content had shrunk to about 1 per cent in each of the soils and after 100 days, as shown in Table 8, it had been reduced still further to about 0.3 per cent or 0.4 per cent. Thus, after three months about 10 per cent of the water-soluble salts originally present was still located in the fertilizer band. The balance had either been rendered insoluble in water, had spread into the surrounding soil, had been leached out altogether, or had been removed by the plants.

In the coarse sand to a distance of five inches to the sides of the row and to a depth of at least fifteen inches below the surface, and probably much deeper, the amounts of soluble salts were in excess of those found at similar points in the unfertilized rows. The evidence is clear that more salt was present also in the fine sandy loam surrounding the fertilizer bands than at corresponding points in the unfertilized rows but in this case for a distance of only three inches in each direction from the fertilizer band. In the sandy clay loam this distance from the point of application was even less.

In order to gain an idea of the proportion of the water-soluble salts in the fertilizer application remaining in that condition in the row as a whole, the amounts by which the determinations shown in Table 8 exceed their appropriate checks were totaled and to this total was added interpolated

amounts for the intermediate soil. From these calculations it appears that at least one-half of the water-soluble fertilizer placed in the coarse sand was still present somewhere in the row in a water-soluble condition. In the other soils, however, it is clear that a large proportion of the fertilizer is no longer present in a water-soluble condition.

Of the three soils used, the coarse sand has the least capacity for reverting phosphates, absorbing soluble salts and resisting leaching, but nevertheless at this time it contained the largest quantity of water-soluble salts. The salts were also much more widely dispersed throughout the row. Therefore it seems probable that considerable proportions of the soluble fertilizer in the other soils have been rendered insoluble in water and remain in this condition within a few inches of the point of application. This fertilizer may be just as available to the plant as before but it will no longer move about with the soil moisture.

CONCENTRATION OF THE SOIL SOLUTION

Sand cultures in pots were made under controlled moisture and temperature conditions to study the salt concentration of the solutions in contact with cotton seed most favorable to germination of seed and growth of young plants. The results of thes pot experiments are interesting in connection with the concentration of fertilizer salts resulting from various placements of fertilizers in relation to the seed in the field experiments reported in this paper.

In the pot tests, under optimum conditions of moisture and temperature, delinted Acala cotton seed germinated most rapidly and grew most vigorously, as shown in Figure 10, when the pure quartz sand was moistened

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Figure 10.- Cotton plants growing in pure quartz sand moistened to 45 per cent of its holding capacity with soil solutions of various concentrations. Each soil solution contained the same proportions but the percentage of total salts was different in each case as shown

to 45 per cent of its holding capacity with solutions containing between 0.05 per cent and 0.2 per cent of soluble salts, which included balanced proportions of all the essential ions. The use of solutions containing less than 0.05 per cent or more than 0.2 per cent of salts resulted in progressively slower appearance of seedlings above ground and slower growth. No plants came up when a solution containing 3 per cent of fertilizer salts was used. These results obtained under controlled conditions check very well with the field results which therefore have greater significance than they otherwise would. The concentrations of the soil solutions in contact with the seed and roots of the small plants in the field are compared with the corresponding stand counts in Tables 9 and 10. The lowest concentrations found in the field were those of the soil solutions of the unfertilized rows and these already contained sufficient salts to insure rapid come-up. As the concentration increased the rate of appearance of seedlings at the surface decreased. The numbers obtained in the first germination count were reduced to one-half in each soil when the concentration approached 0.3 per cent. Germination was considerably delayed by concentrations between 0.3 per cent and 1.0 per cent, but the final stand was nevertheless as good as that on the unfertilized plats where the concentration of soluble salts did not at any time exceed 1 per cent. Beyond this point the final stand was reduced. A few plants grew in contact with the soil solution temporarily containing 3 per cent of soluble salts. Growth appeared to be most rapid when the concentration was about 0.2 per cent.

Seed and seedlings were examined from time to time during the first month after planting. On April 22 or six days after planting in the very fine sandy loam, seedlings were carefully removed from the soil. Between

20 and 25 were gathered for each of a number of placements of the fertilizer and typical plants are shown in Figure 11. No signs of germination

Figure 11.- Typical plants on April 22, or 6 days after planting, for various placements of 800 pounds per acre of 4-8-4 fertilizer in Norfolk very fine sandy loam. Left to right top row; no fertilizer, 1.75" band 4" below seed, 1.75" band 3" below seed, 1.75" band 2" below (seed pressed into soil and covered loosely), 1.75" band 2" below, 1.75" band 1" below, 3.5" band 1" below. Bottom row; 1.8th contact 7/8 $3\frac{1}{2}$" to sides, 1/4th contact 3/4 sides, all contact, mixed with soil below seed, bands $1\frac{1}{2}$" to each side 2" below level, bands $3\frac{1}{2}$" to sides 2" below level.

were observed in any of the seed found in contact with the full rate application. Very tiny roots (see fig. 11) were found, however, on most of the seed in contact with one-fourth or one-eighth of the fertilizer application or at a rate of 100 to 200 lbs. per acre. Where the fertilizer was placed one and two inches below the seed, the plants were smaller than the check plants. The concentrations of the soil solutions in the seed zones two days earlier were 1.0 per cent and 1.4 per cent for the 1.75 and 3.5-inch bands placed 1 inch below the seed and 0.2 per cent and 0.28 per cent for those placed 2 inches below the seed. Where the fertilizer was located $3\frac{1}{2}$ inches to the sides of the seed, the size and condition of the seedlings were about the same as those of the checks, which averaged 3 inches in length at this time. In all four cases where the fertilizer was placed $1\frac{1}{2}$ inches to the sides of the seed and in the case of the 3.5-inch band 4 inches below the seed, the plants were larger than the unfertilized ones. This was especially noticeable where the fertilizer was $1\frac{1}{2}$ inches to the sides on a level one inch below that of the seed. In the latter case the plants were about 4 inches in length and the concentration of salts in the soil solution on April 20 was 0.159 per cent. The plants about 3 inches in length were in contact at that time with soil solutions with concentrations of 0.08 per cent to 0.11 per cent.

Seedlings from the same plats were examined for a third time on May 4. Typical plants are shown in Figure 12. In no case where the

Figure 12.- Typical plants on May 4 or 18 days after planting for various placements of 800 pounds per acre of 4-8-4 fertilizer in Norfolk very fine sandy loam. Left to right top row; no fertilizer, 1.75" band 4" below seed, 1.75" band 3" below seed, 1.75" band 2" below (seed pressed into soil and covered loosely), 1.75" band 2" below, 1.75" band 1" below, 3.5" band 1" below. Bottom row; 1/8th contact 7/8 $3\frac{1}{2}$" to sides, 1/4th contact 3/4 sides, all contact, mixed with soil below seed, bands $1\frac{1}{2}$" to each side 2" below level, bands $3\frac{1}{2}$" to sides 2" below level

fertilizer was put below the seed in this soil were the plants, the roots of all of which were now in contact with soil solutions of greater concentration than 1 per cent, as large on the average as the unfertilized checks. Those fertilized at the sides were larger. The check plants averaged $5\frac{1}{2}$ inches, and those fertilized $1\frac{1}{2}$ and $3\frac{1}{2}$ inches to the sides about $7\frac{1}{2}$ and $6\frac{1}{2}$ inches in length, respectively. The concentrations of the soil solutions in contact with the roots for these placements appear to have been about 0.10 per cent, 0.30 per cent, and 0.15 per cent, respectively.

Seedlings from the coarse sand were examined on April 28. At that time, 5 days after planting, the check plants were $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in length. None of those with fertilizer placed below the seed either in narrow bands or mixed with the soil were that large. Those with the fertilizer located $3\frac{1}{2}$ inches to the sides of the seed at all levels tried and $1\frac{1}{2}$ inches to the sides at a level 3 inches below the seed were about the same in size as the unfertilized plants. Those with bands $1\frac{1}{2}$ inches to the sides and one inch below the seed level (soil solution concentration 1.21 per cent) were smaller than the checks (soil solution concentration 0.06 per cent) and those with the same bands $1\frac{1}{2}$ inches to the sides and 2 inches below the seed level (soil solution concentration 0.09 per cent) were the largest of all, measuring $1\frac{3}{4}$ inches in length on an average.

ROOT SYSTEM

Fertilizer should be placed where the roots can obtain the optimum amount of food throughout the season and where it will not injure the root system. A number of observations, made during the present study, have some bearing upon these points.

Two weeks after planting, in the present experiments, seed had germinated where the fertilizer was placed one inch below them but in the lighter soils few of the seedlings had pushed through the surface and most of them had shriveled root tips. A considerable proportion of the plants resulting with placements of fertilizer two inches below the seed or mixed with the soil also had shriveled root tips. One month after planting only a few of these plants were still living in the coarse sand and fine sandy loam although in the sandy clay loam no injury was observed from the same placements. Such dead plants as were examined clearly showed injury to the primary root and no lateral roots were visible.

When the primary root encountered the fertilizer band at depths of three and four inches below the seed zone in the lighter soils lateral roots had appeared and although the tip of the primary root was killed many plants continued to grow. Although seedlings from all of the placement tests were examined the only case of injured roots observed in the sandy clay loam was where 8-16-8 fertilizer at the rate of 600 pounds per acre was placed 2 inches below the seed. With this high rate of application, however, the end of the tap root of the majority of the seedlings was dead where it encountered the fertilizer zone. These plants had plenty of lateral roots in a healthy condition and one month after planting appeared to be growing as vigorously as any of the other plants.

The above observations seem to show that if the concentration of soluble salts seriously injures the tap root before any laterals have developed, the plant dies.

No injury to the roots was observed as a result of side placements in any case. Since during early growth the development of lateral roots is slow as compared with that of the tap root, it is unlikely that any lateral roots would reach the fertilizer band even at the $1\frac{1}{2}$ inches-to-the sides placement until a network of other roots was established.

Three months after planting a mass of root hairs had formed around the fertilizer band in all of the placements and in all of the soils. Regardless of the position of the fertilizer, a mat of interlacing root hairs developed around that point. The large roots were distributed throughout the soil and sub-soil without any apparent reference to the position of the fertilizer.

YIELD

In considering the yields of seed cotton in Tables 11 and 12, it should be borne in mind that the rainfall was below normal for the season and that early adverse weather conditions for the very fine sandy loam and coarse sand not only caused injury to germination but caused a large number of the young seedlings to die. As indicated in the yield tables by the number of mature plants, the stand was excellent on the sandy clay loam, satisfactory in a number of tests on the coarse sand, but rather inferior on the very fine sandy loam. For the tests having only a few mature plants per 50-foot row, attention has been called to the severe injury to germination and obviously their yields need not be discussed.

PLACEMENT

On the Norfolk very fine sandy loam and the coarse sand, highest yields were obtained where the fertilizer was placed to the sides of the seed and where placed in a band 3 or more inches below the seed (see Table 11). The side placement was slightly superior. There is some indication that fertilizer placed in bands at the sides of the seed should be 2 or 3 inches below the level of the seed. The lower yields in all cases were accompanied by poorer stands. On the Cecil sandy clay loam where good stands were secured in all cases except where the fertilizer was applied in contact with the seed, highest yields were obtained with the shallower placements. On this heavy soil fertilizer applied in bands below the seed resulted in higher yields than fertilizer applied in bands at each side of the seed. Mature cotton plants fertilized with 800 pounds per acre of 4-8-4 fertilizer in a 1.75-inch band at various depths below the seed are shown, for the Norfolk very fine sandy loam, coarse sand, and Cecil sandy clay loam, in Figures 13, 14, and 15, respectively.

Figure 13.- Mature cotton plants on Norfolk very fine sandy loam fertilized with 800 pounds per acre of 4-8-4 mixture applied in a 1.75-inch band (a) 4 inches below the seed, (b) no fertilizer, (c) 3 inches below the seed; (d) 2 inches below the seed

Figure 14. - Mature cotton plants on Norfolk coarse sand fertilized with 800 pounds per acre of 4-8-4 mixture applied in a 1.75-inch band (a) 4 inches below the seed, (b) 3 inches below the seed, (c) 2 inches below the seed (seed pressed into furrow and covered with loose soil), (d) 2 inches below seed (normal planting), (e) 1 inch below seed, (f) no fertilizer

Figure 15,- Mature cotton plants on Cecil sandy clay loam fertilized with 800 pounds per acre of 4-8-4 mixture applied in a 1.75-inch band; (a) 3 inches below the seed, (b) no fertilizer, (c) 2 inches below the seed, (d) 1 inch below the seed, (e) in contact with seed

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Application of 1/8 or 1/4 of the total fertilizer in contact with the seed and the remainder either in bands 2 inches or 3 inches below the seed or in bands 3½ inches to each side of the seed usually resulted in

reduced yields as compared to yields obtained where all of the fertilizer was applied in the corresponding placements some distance from the seed. On the Norfolk coarse sand some increase in yield was obtained where 1/8 of the fertilizer was applied in contact with the seed but application of 1/4 of the total fertilizer in contact with the seed resulted in reduced yield.

Mixing the fertilizer with the soil did not result in increased yield. There is an indication that the opportunity to plant seed on firm soil is one of the advantages of application of fertilizer at the sides of the seed. Reduction in yield followed where the band of soil below the seed, which normally would be undisturbed when fertilizer is applied at the sides of the seed, was stirred just before the seed were planted. Some increase in yield was obtained where the seed were pressed in the furrow and covered with loose soil.

RATE OF APPLICATION

The application of 8-16-8 fertilizer at 200, 400 and 600 pounds per acre, as shown in Table 12, gave the highest yield for each rate on the sandy clay loam soil when the fertilizer was placed 3.5 inches to each side of and 2 inches below the level of the seed. The same was true on the sandy soils for 400 and 600 pounds per acre. However, at 200 pounds per acre on the sandy soils, mixing the fertilizer with the soil was slightly superior to and the 1.75-inch band 2 inches below the seed was equally as good as the side placement.

Failure to secure full benefit from increased rate of application of fertilizer due to method of application is indicated in Table 12. On the sandy soils increasing the rate of application of 8-16-8 fertilizer from 200 to 400 and 600 pounds per acre resulted in reduced yields where

the fertilizer was applied in bands $1\frac{3}{4}$ inches wide and 2 inches below the seed or where the fertilizer was mixed with the soil. Poor stands with the higher rates of fertilization where these placements were used was the principal cause of the reduced yields. Where the fertilizer was applied in bands at the sides of the seed, increasing the rate to 400 pounds per acre resulted in increased yield but further increase in rate of application gave no further increase in yield.

On the Cecil sandy clay loam the three placements at the same rate of application produced approximately the same yields.

Single Versus Double Strength Fertilizers

Yields (Tables 11 and 12) obtained with corresponding placements where 800 pounds per acre of 4-8-4 and 400 pounds per acre of 8-16-8 fertilizer were used showed no significant differences.

SUMMARY

This paper is the third of a series presenting results of studies on methods of applying fertilizers to cotton in South Carolina.

Under the conditions prevailing in 1931, applications of 800 pounds per acre of 4-8-4 fertilizer drilled either in bands 1.5 or more inches to each side or 4 inches directly below the seed had no apparent injurious effects on germination.

On Cecil sandy clay loam appearance of seedlings was greatly delayed and the final stand was seriously reduced only when all the fertilizer was placed in contact with the seed but on Norfolk coarse sand and Norfolk very fine sandy loam this occurred also when the fertilizer was placed below the seed either in bands at depths of three inches or less or when mixed with the soil and when 1/8 or 1/4 of the fertilizer was placed in contact with the seed.

Movements of soluble salts in the sandy soils from the original position of the fertilizer into the seed zone during the germination period were insignificant from placements at the sides but serious from placements directly below the seed. The degree of delay or injury to germination bore a close relationship to the amount of soluble salt carried into contact with the seed.

Seedlings came up most rapidly when the method of application produced a soil solution in contact with the seed containing between 0.05 and 0.2 per cent of soluble salts. When the placement produced a soil solution in contact with the seed containing from 0.3 to 1.0 per cent of salts, germination was progressively delayed and when the solution contained 3.0 per cent or more no plants came up.

The distance to which soluble salts spread from the point of application was greater in the coarse sand than in the sandy clay loam.

The highest yields were obtained with side placements on the sandy soils but on the clay loam with heavy rainfall during the germination period the highest yields were obtained with bands placed 1 inch below the seed although good yields were also produced with side placements in this soil.

There was no advantage of either mixing the normal amount of fertilize with the soil as accomplished in these tests or placing 1/8 or 1/4 of the application in contact with the seed and the balance at the sides or below the seed.

Equivalent amounts of the 4-8-4 and 8-16-8 fertilizers produced similar results.

On the sandy clay loam where final stand was good, increasing the rate of application of the 8-16-8 fertilizer from 200 to 400 and 600 pounds per acre gave increased yields for the three representative placements but

on the very fine sandy loam and coarse sand increased yields were obtained only when the fertilizer was placed in bands 3.5 inches to each side and 2 inches below the level of the seed. Due to the reduction in stand at the higher rates, placements below the seed and mixed with the soil on the sandy soils gave reduced yields.

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